

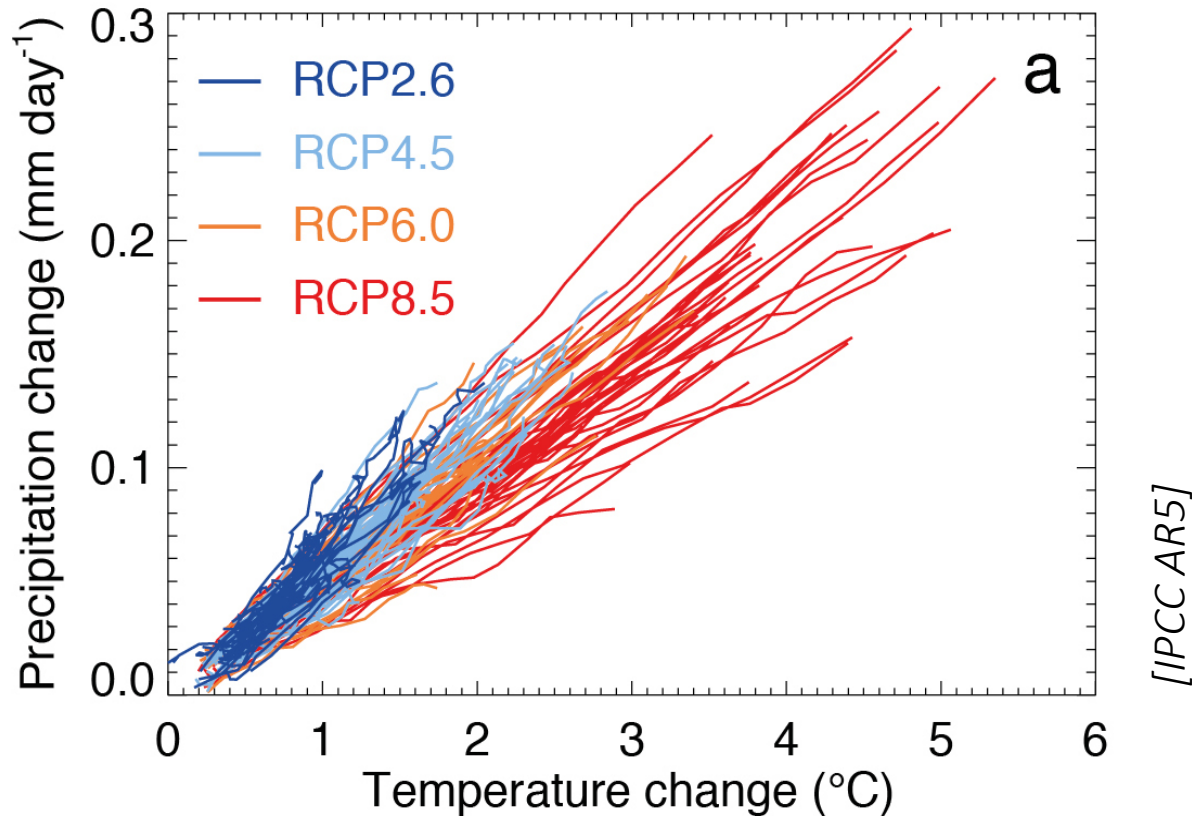
Physical constraints and *modeling uncertainties* on the intensification of the global hydrologic cycle

Benjamin Fildier, LMD, Paris
William D. Collins, UC Berkeley, LBNL

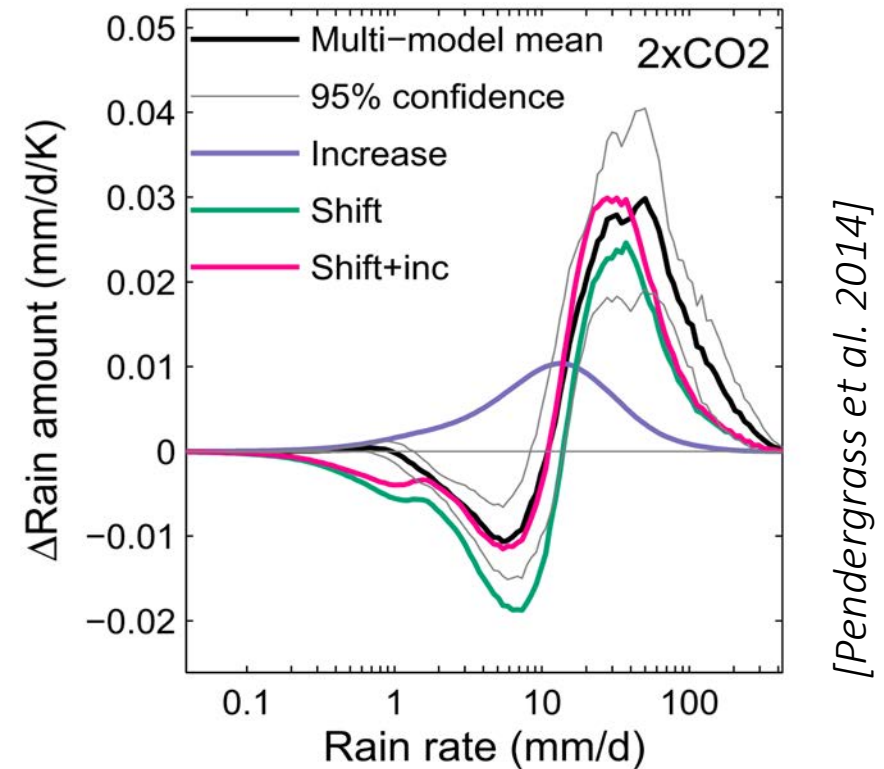


Can we improve GCMs' accuracy in global precipitation change?

Strong GCM disagreements

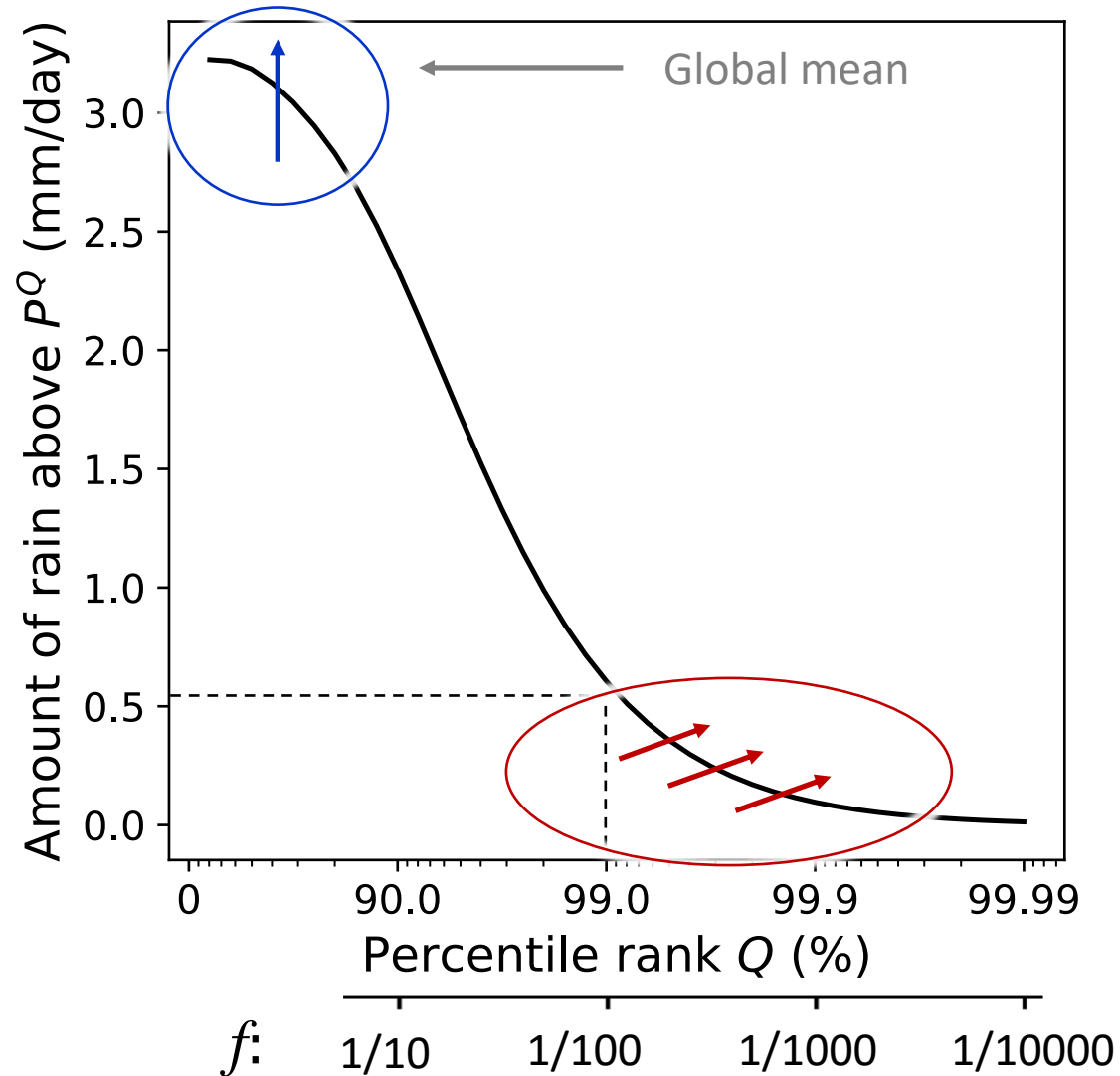


Shifts in the rain distribution



Use physical “scaling” that connect precipitation changes to sources of uncertainty

The **energy constraint** (radiative cooling)
drives an increase of 2-3%/K in mean rain [Allen&Ingram (2002)]
mainly affects the weakest rain rates [Chua et al. (2019)]



Thermodynamic increase in BL humidity (Clausius-Clapeyron, 6-7%/K)

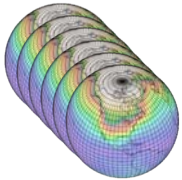
Changing atmospheric **dynamics** could lead to departures from CC

Total error

Intermodel disagreements

General model bias

$$\mathbb{E}(X_m - X_{\text{true}})^2 = \mathbb{E}(X_m - \bar{X})^2 + \mathbb{E}(\bar{X} - X_{\text{true}})^2$$



vs.



model predictions for \bar{P} , P_{99} , ...

multi-model mean

Uncertainty from resolved and unresolved processes

Cloud
microphysics



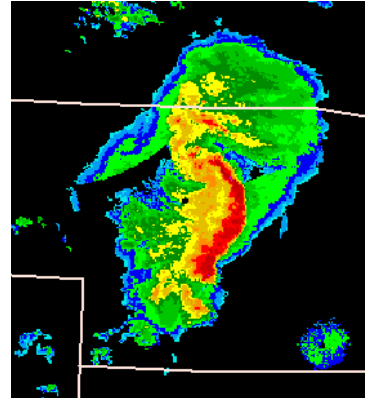
Turbulence



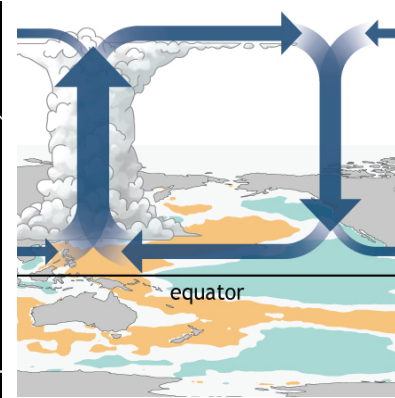
Convection



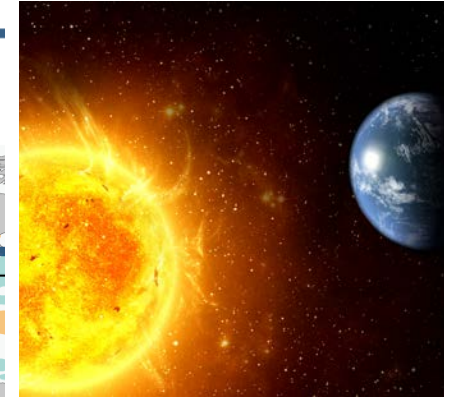
Mesoscale
organization



Synoptic
circulation



Global energy
balance



mm-cm

10-100m

10-100km

100-1000km

Global Climate Models (CMIP models, CAM)

Cloud-Resolving Model (SAM)

Superparameterized Model (SPCAM)

Embedded CRMs

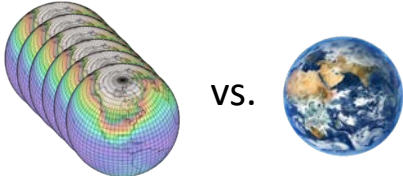
Outer GCM

Using simple physical scalings to pinpoint sources of error

1. Inter-model spread in **mean rainfall**
from radiative transfer parameterizations
2. Possible model biases in **extreme rainfall**
from the coupling between convection and circulation

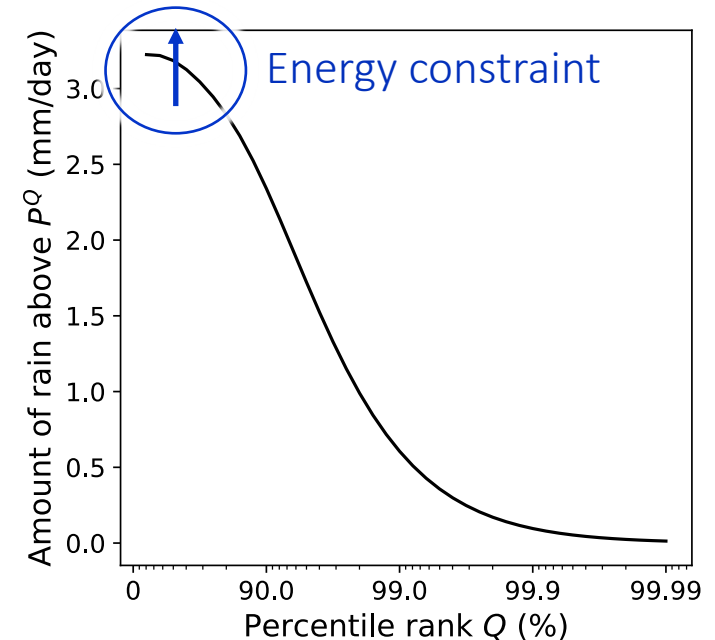
Using simple physical scalings to pinpoint sources of error

1. Inter-model spread in **mean rainfall**
from radiative transfer parameterizations
2. Possible model biases in **extreme rainfall**
from the coupling between convection and circulation



vs.

$$\mathbb{E}(X_m - X_{\text{true}})^2 = \underbrace{\mathbb{E}(X_m - \bar{X})^2}_{\text{Inter-model variance}} + \underbrace{\mathbb{E}(\bar{X} - X_{\text{true}})^2}_{\text{General bias}}$$



Uncertainties in mean rainfall

Change in:		Precipitation	Longwave cooling	Shortwave heating
(W/m ² /K)		$\frac{L_v \Delta P}{\Delta T}$	$= \frac{\Delta LW_c}{\Delta T}$	$- \frac{\Delta SW_{\text{abs}}}{\Delta T}$
CMIP5 multi-model	mean	+1.3	-2.7	+1.1
	spread	1.0	1.5	0.9

Uncertainties in mean rainfall

Change in:

(W/m²/K)

Precipitation

$$\frac{L_v \Delta P}{\Delta T}$$

=

Longwave cooling

$$\frac{\Delta LW_c}{\Delta T}$$

Shortwave heating

$$- \frac{\Delta SW_{\text{abs}}}{\Delta T}$$

CMIP5 multi-model {
mean
spread

+1.3

1.0

-2.7

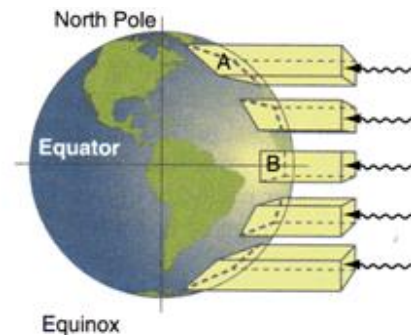
1.5

+1.1

0.9

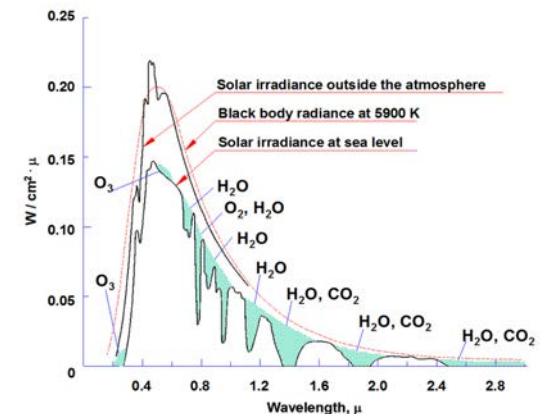
Explained by different water-vapor / lapse-rate
feedback strengths [*Pendergrass & Hartmann (2013)*]

Spatial distribution of
absorptive species?

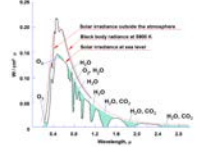


OR

Radiative transfer
schemes?

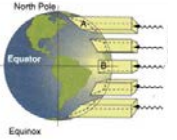


Emulating the behavior of radiative transfer codes



Radiation parameters

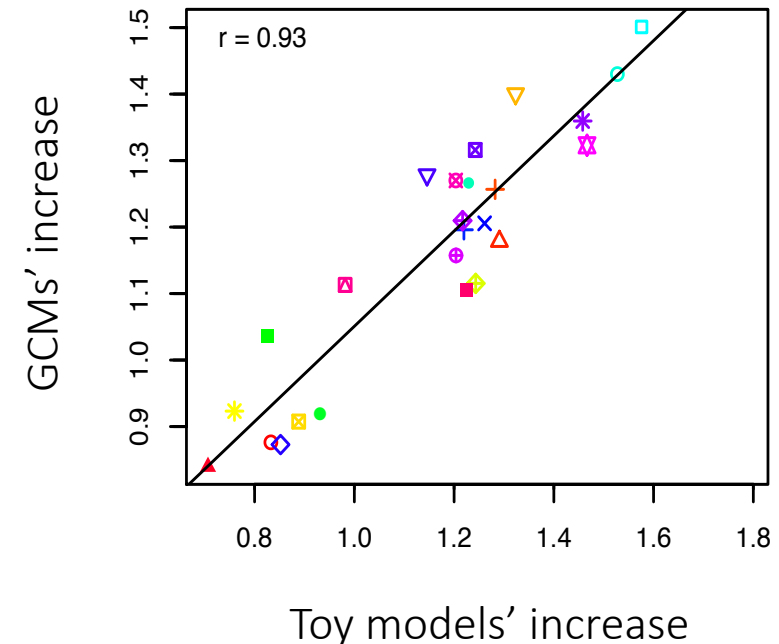
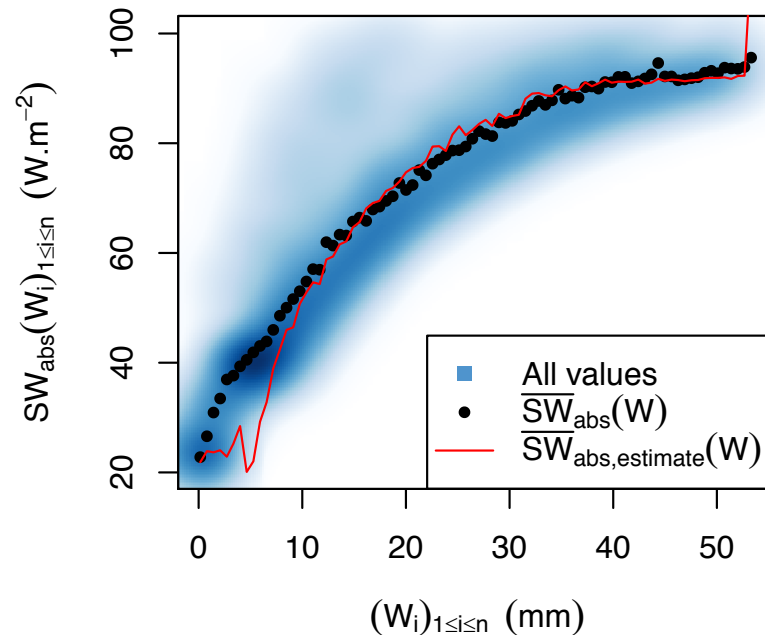
Distribution of water vapor



$$SW_{\text{abs}} = \alpha S \int_{\mu, W} \mu \left(1 - e^{-(\kappa W + \beta)/\mu} \right) f(\mu, W) d\mu dW$$

Fit α , κ and β for each model in the present climate

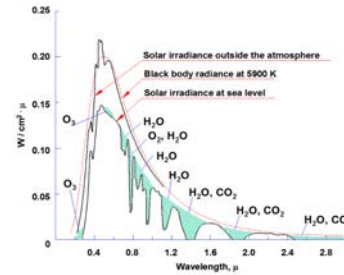
Use them to reproduce model disagreements in $\frac{\Delta SW_{\text{abs}}}{\Delta T}$



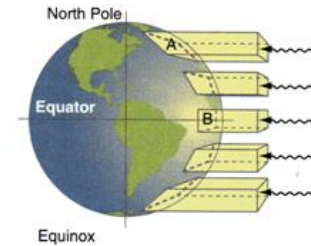
Emulating the behavior of radiative transfer codes

$$SW_{\text{abs}} = \underbrace{\alpha S}_{\text{Radiation parameters}} \int_{\mu, W} \underbrace{\mu}_{\text{Radiation parameters}} \left(1 - e^{-\underbrace{(\kappa W + \beta)}_{\text{Radiation parameters}} / \mu} \right) \underbrace{f(\mu, W)}_{\text{Distribution of water vapor}} d\mu dW$$

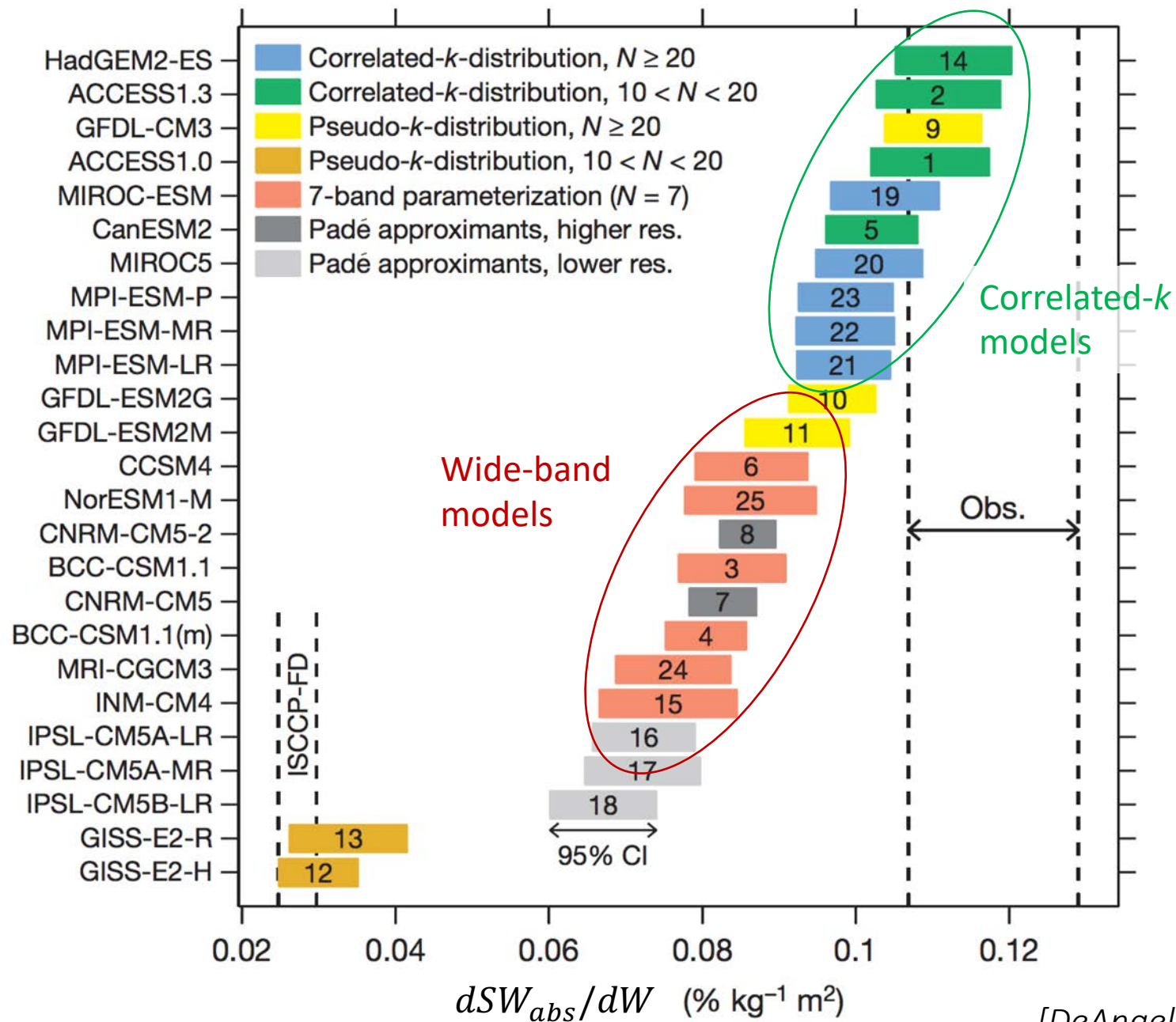
86% of the
multi-model
variance



83%



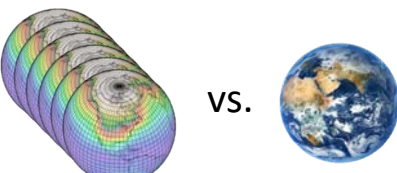
<1%



[DeAngelis et al. (2015)]

Using simple physical scalings to pinpoint sources of error

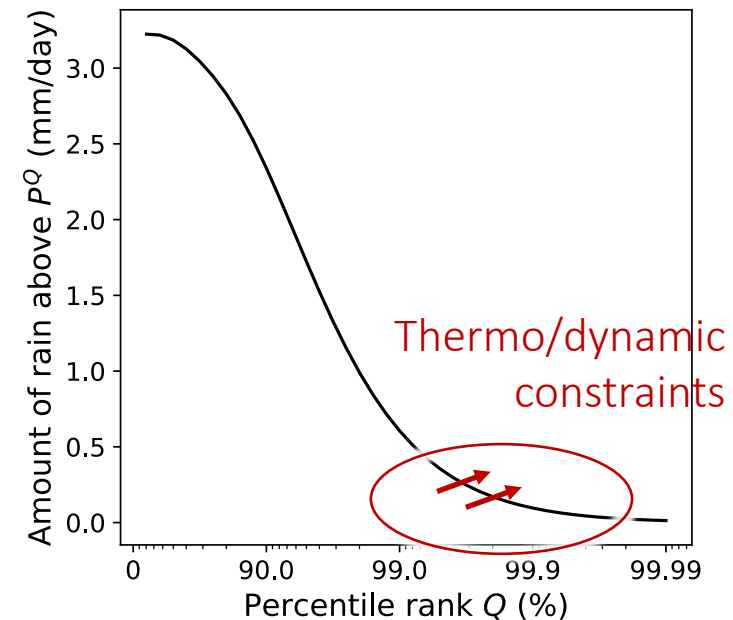
1. Inter-model spread in mean rainfall
from radiative transfer parameterizations
2. Possible model biases in **extreme rainfall**
from the coupling between convection and circulation



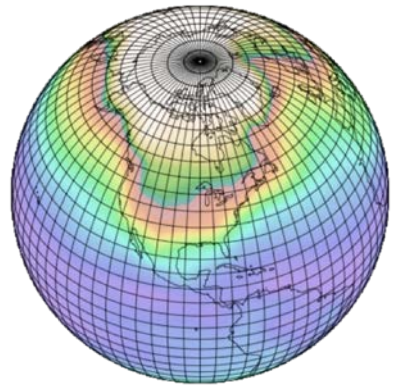
Inter-model variance

General bias

$$\mathbb{E}(X_m - X_{\text{true}})^2 = \mathbb{E}(X_m - \bar{X})^2 + \mathbb{E}(\bar{X} - X_{\text{true}})^2$$



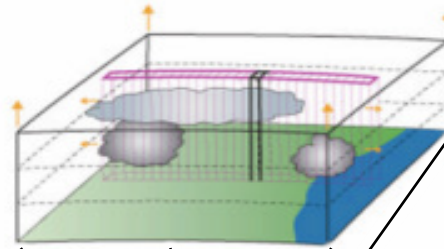
Dynamics of extreme rain events with different representations of convection



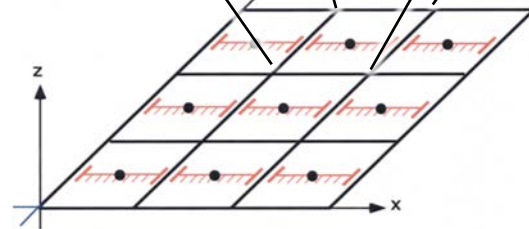
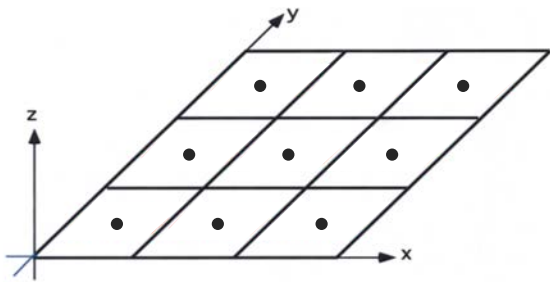
General circulation models (GCMs)



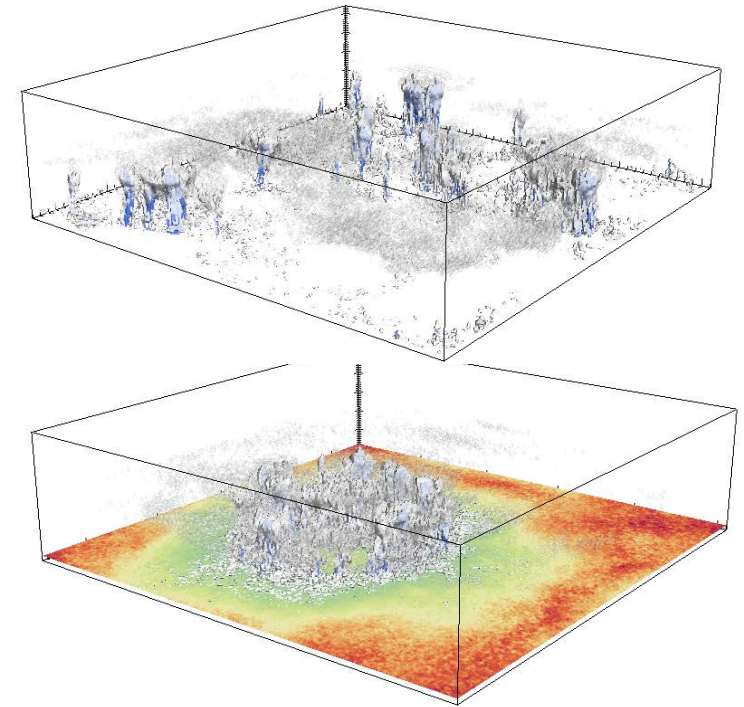
Super-parameterization (SP-CAM)



Parameterized convection (CAM5)



Cloud-Resolving Models (CRMs)



100km-1000km

→ Tropical extremes, in approximate RCE

Idealized square domain in RCE

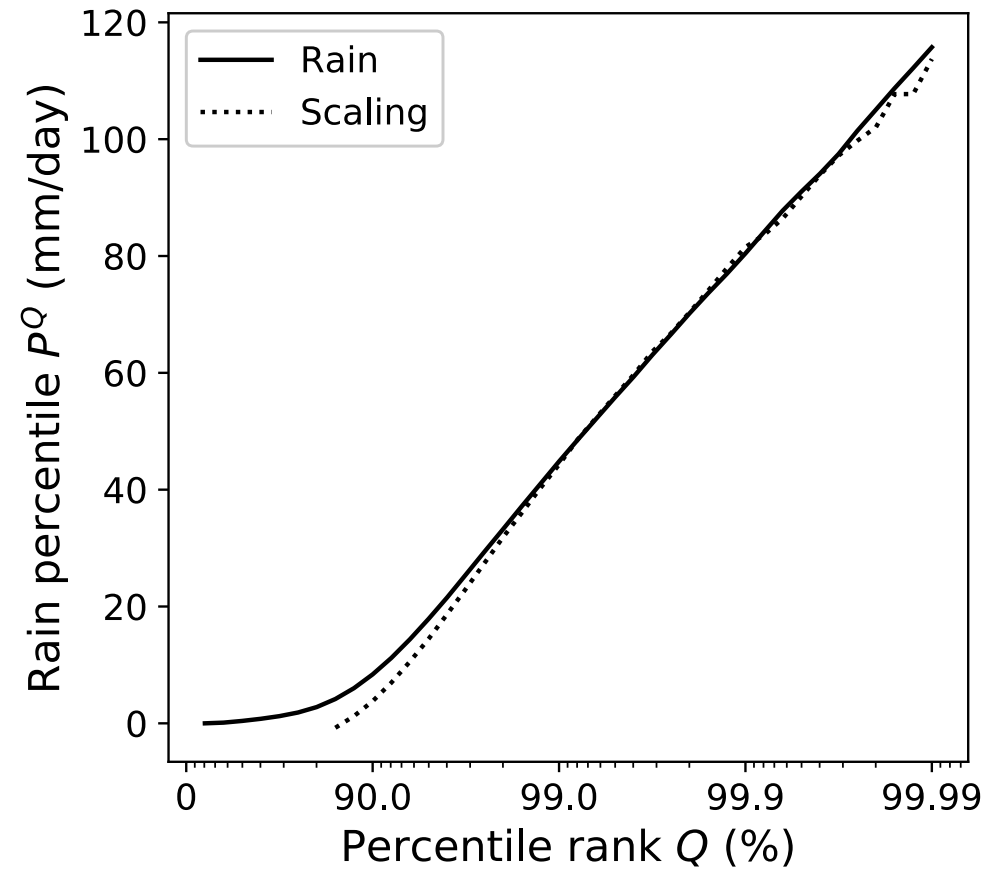
Use scaling for precipitation extremes for model comparison

$$P_e \approx \alpha \left\langle \omega_e \frac{\partial(q_v^*)_e}{\partial p} \right\rangle$$

“extreme” P_e

Composited on extreme events ω_e

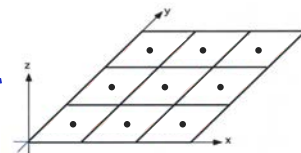
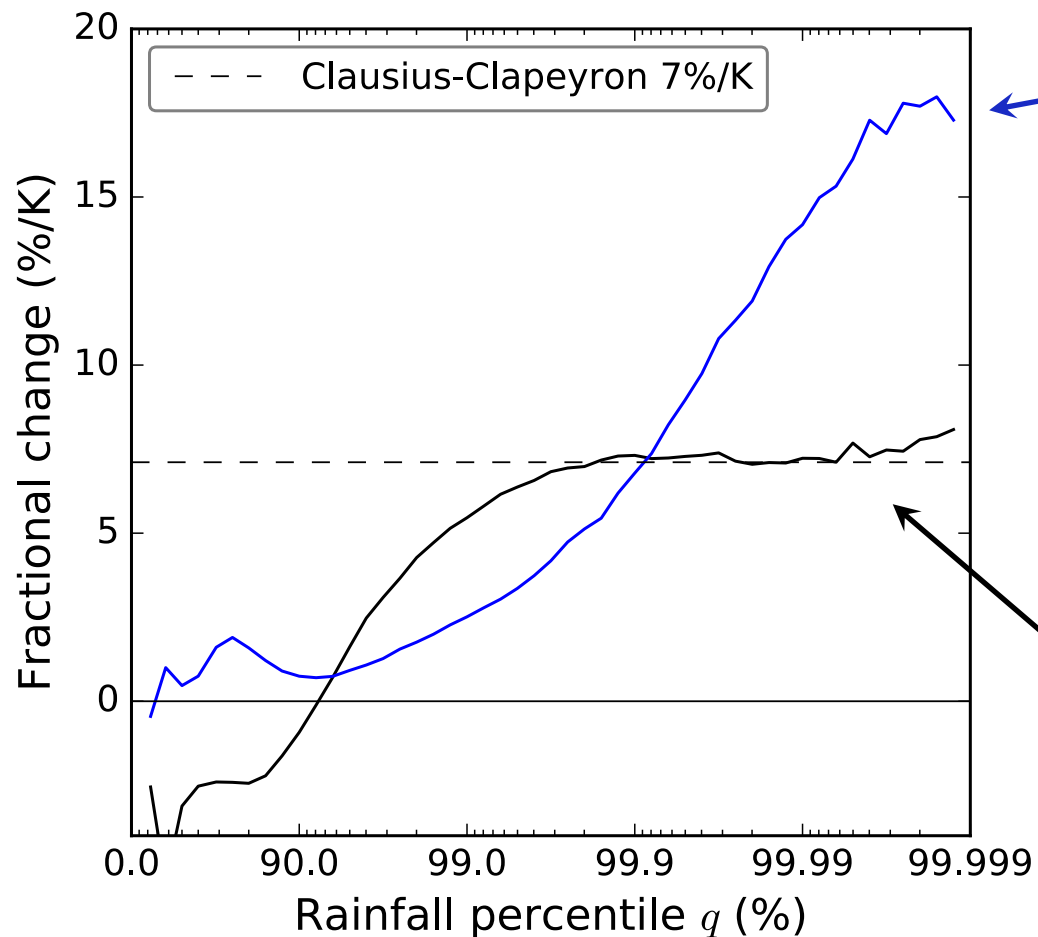
Vertical integral $\frac{\partial(q_v^*)_e}{\partial p}$



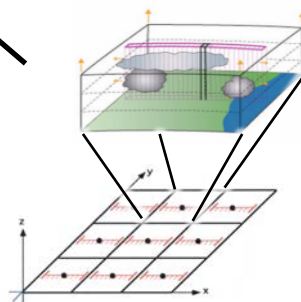
[O’Gorman & Schneider (2009),
Muller et al. (2011),
~Romps (2011)]

Climate models don't always agree with CC

Parameterization (CAM5) vs. super-parameterization (SP-CAM)

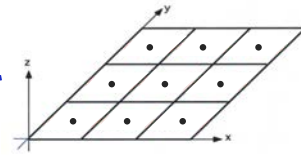
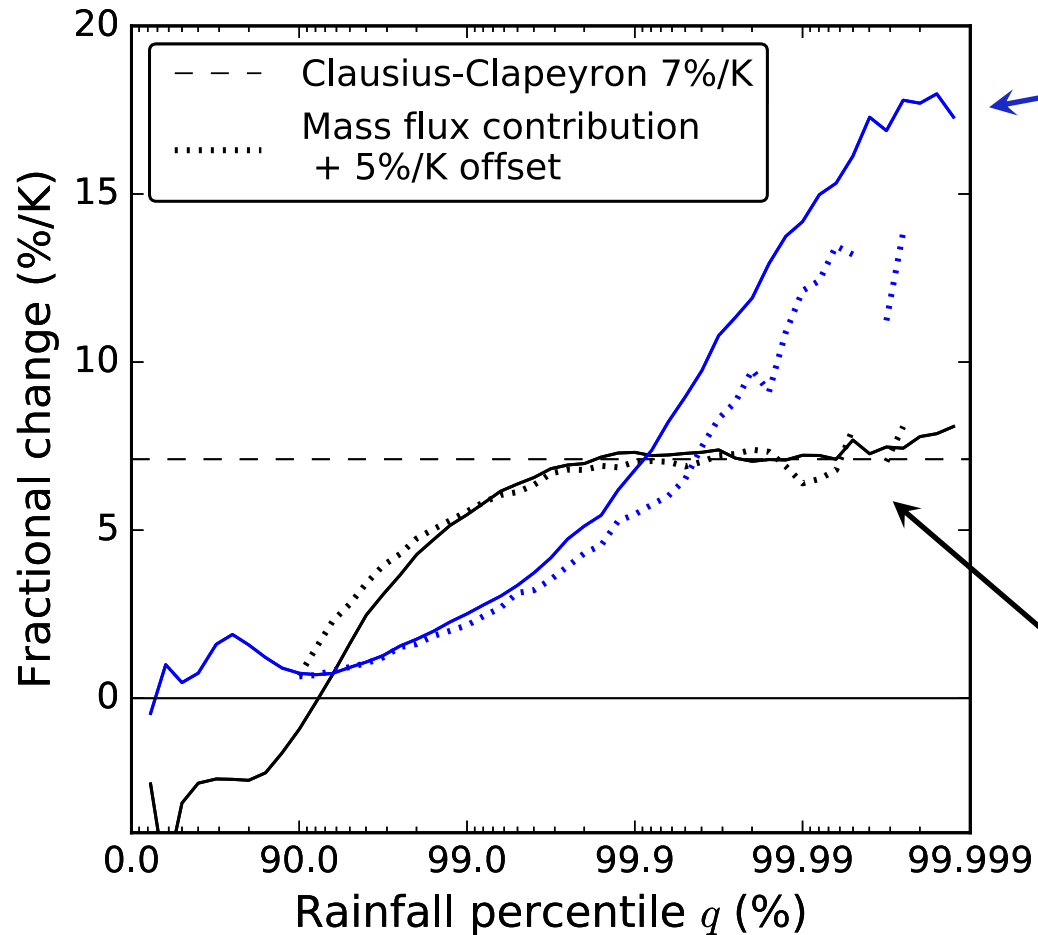


- Better performance of SPCAM tends to give credit to the Clausius-Clapeyron rate.

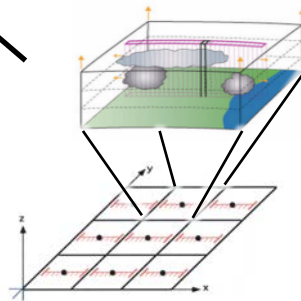


Climate models don't always agree with CC

Parameterization (CAM5) vs. super-parameterization (SP-CAM)



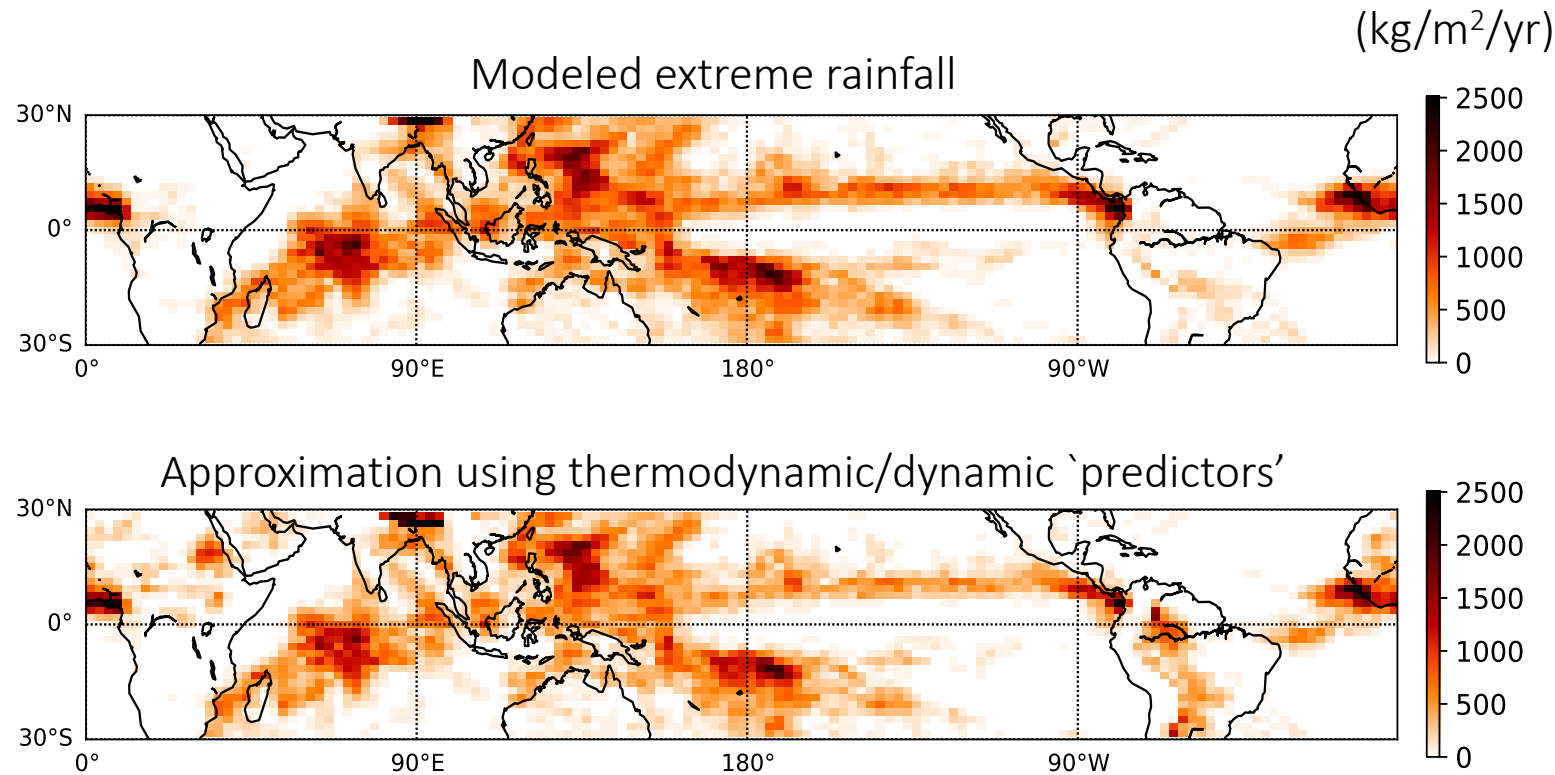
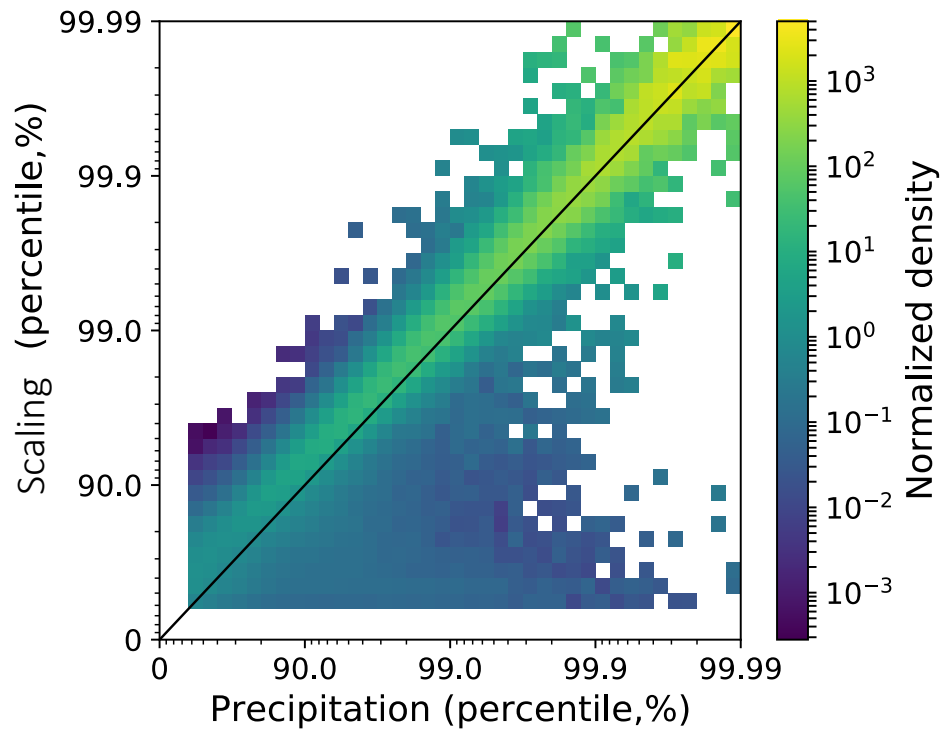
- Better performance of SPCAM tends to give credit to the Clausius-Clapeyron rate.
- The difference arises from how the parameterized convection 'feels' the large-scale vertical motion.



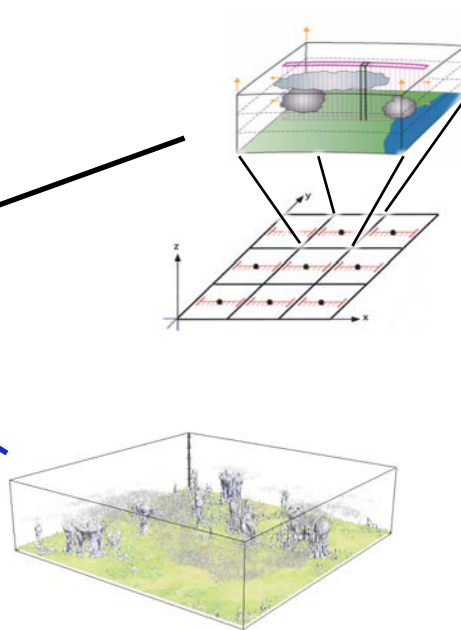
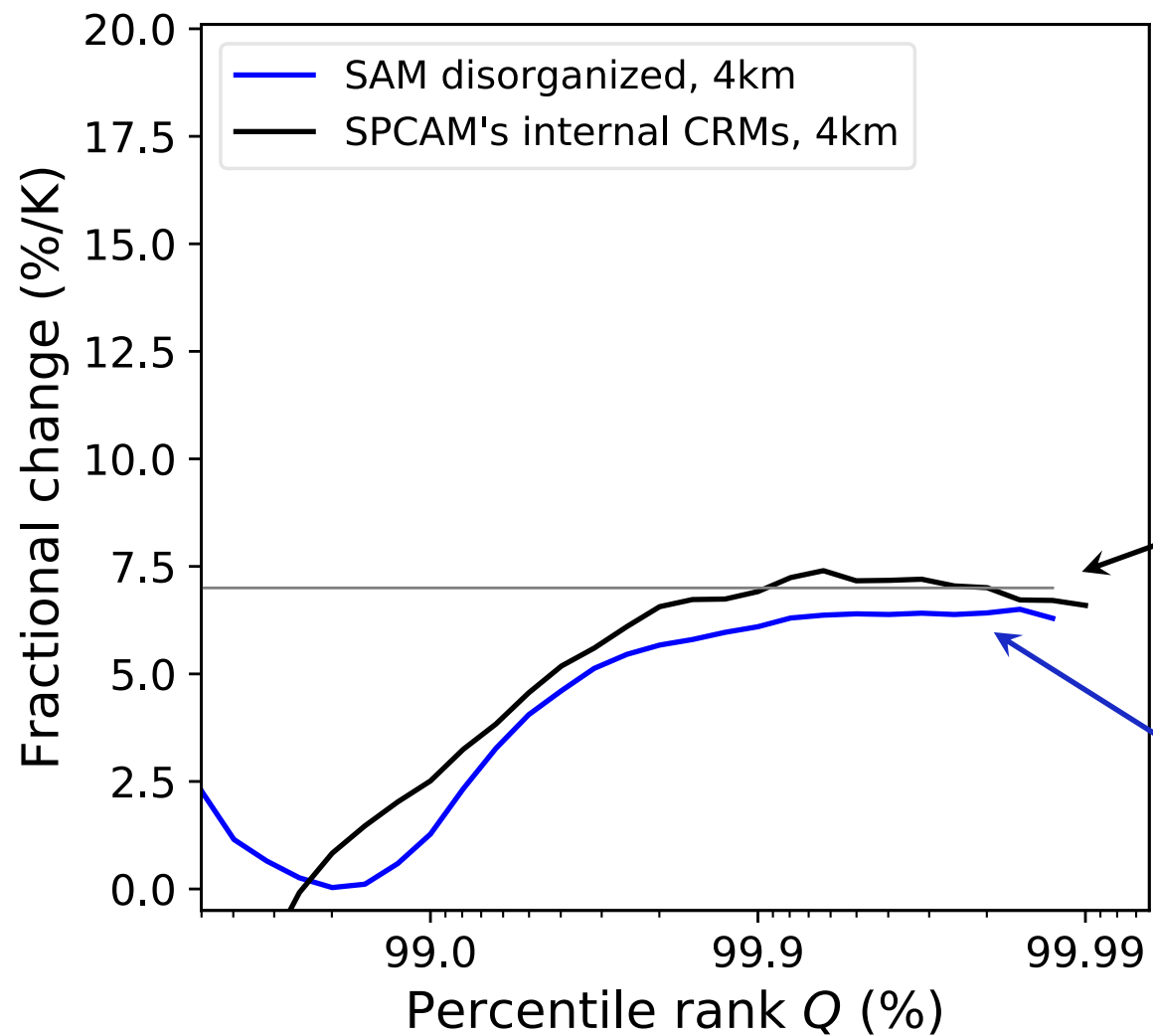
Resemblance between CAM5 and SPCAM

The scaling mimicks the rainfall ‘parameterization’
at the location of extremes in *both* CAM5 and SPCAM

$$P_e \approx \alpha \left\langle \omega_e \frac{\partial (q_v^*)_e}{\partial p} \right\rangle$$

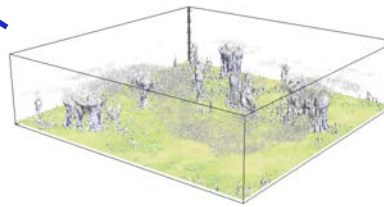
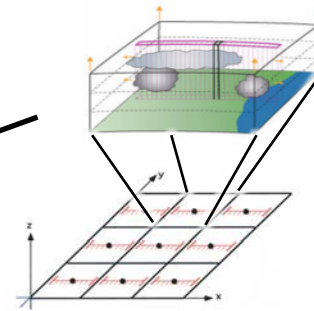
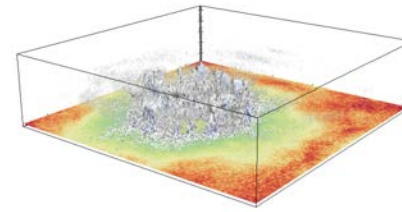
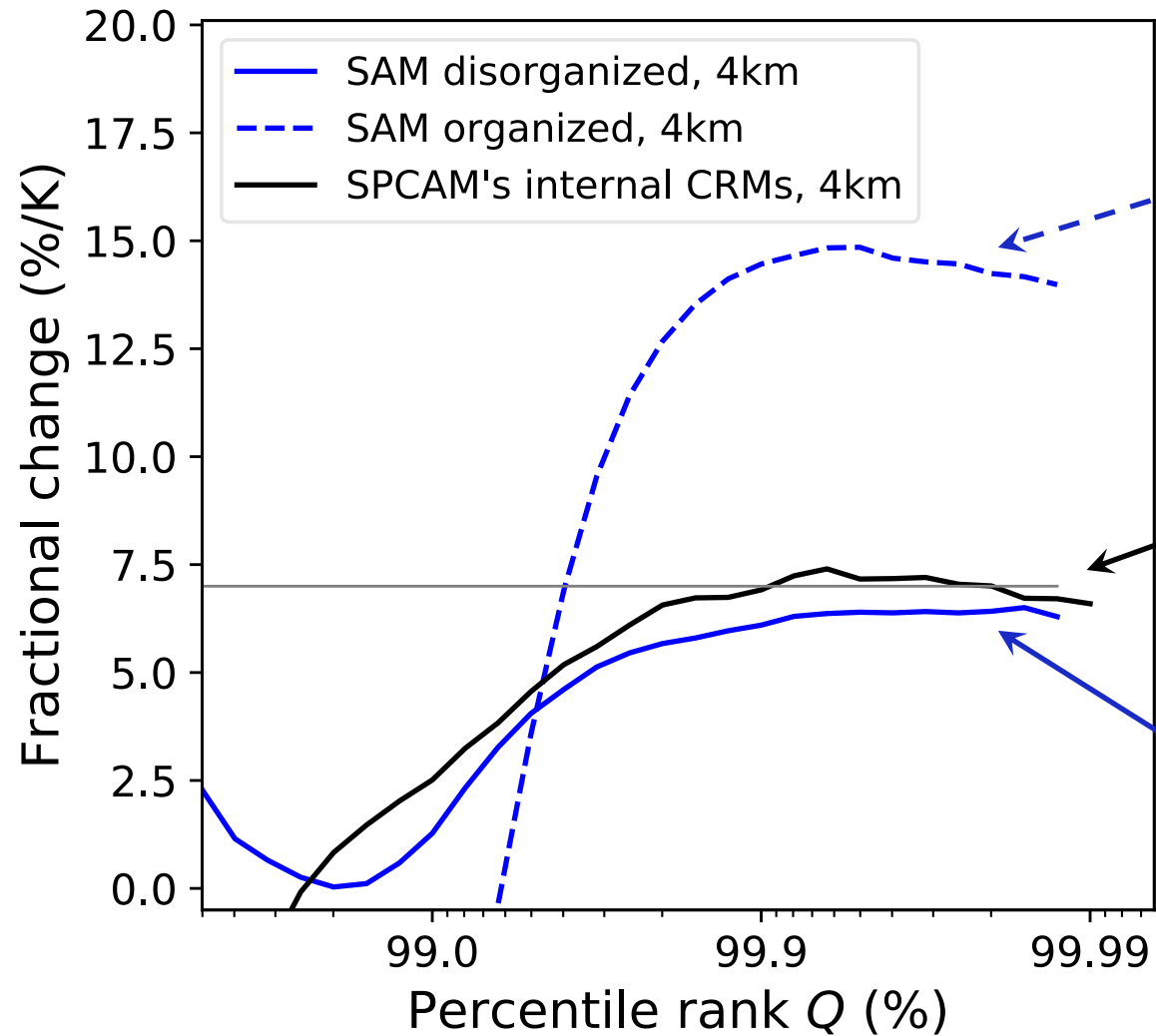


Multiscale coupling btw. convection and the circulation



SPCAM includes large-scale circulations, suggesting that spatial organization on very large scales don't affect convective extremes

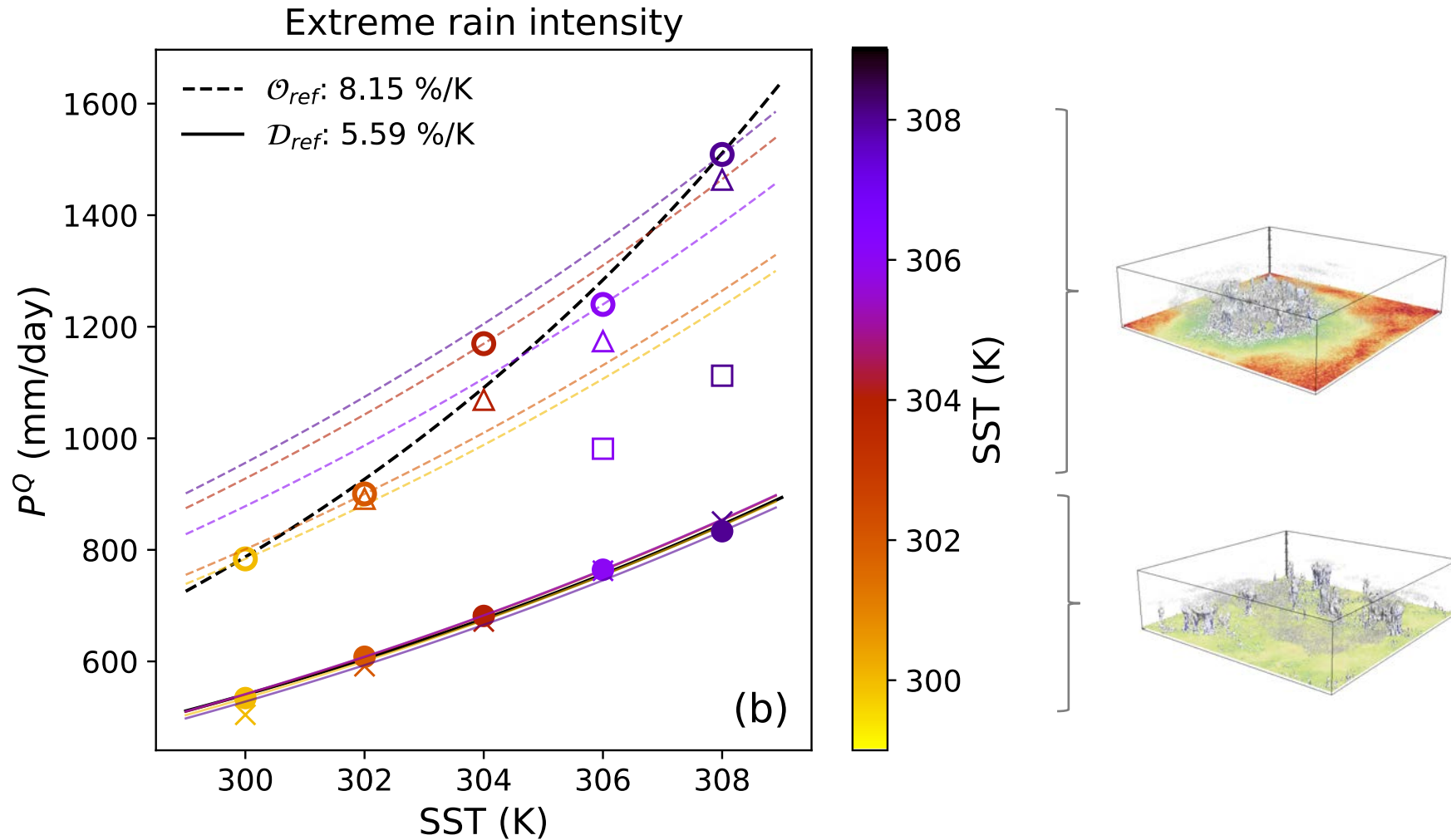
Multiscale coupling btw. convection and the circulation



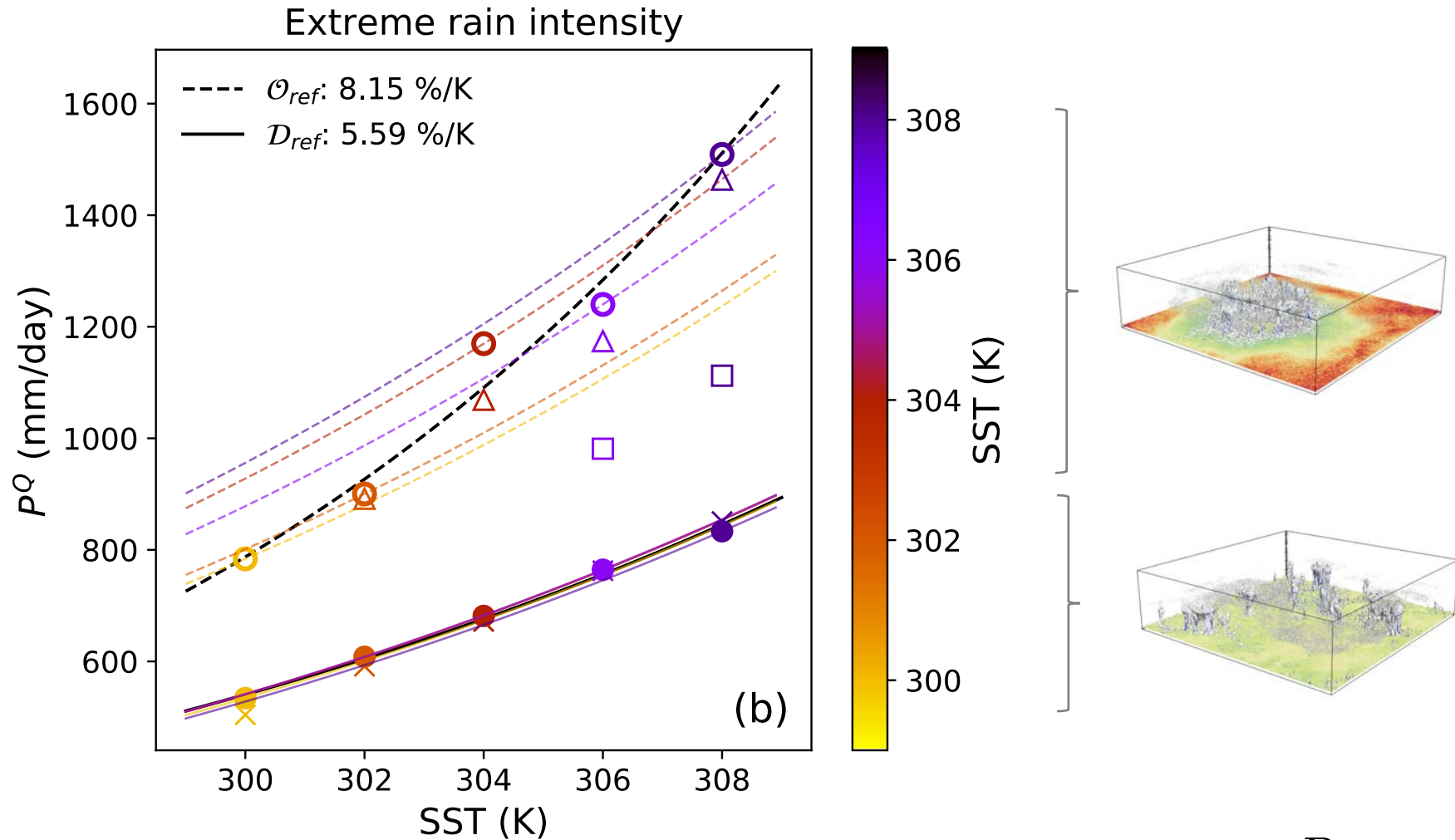
Mesoscale circulations could enhance rainfall extremes beyond CC through increases in precipitation efficiency

SPCAM includes large-scale circulations, suggesting that spatial organization on very large scales don't affect convective extremes

Effect of convective organization on extreme rain



Effect of convective organization on extreme rain



$$P_e \approx \alpha \left\langle \omega_e \frac{\partial (q_v^*)_e}{\partial p} \right\rangle$$

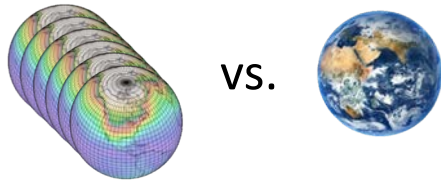
Summing up some structural uncertainties in GCMs

Total error

Model disagreements

General model bias

$$\mathbb{E}(X_m - X_{\text{true}})^2 = \mathbb{E}(X_m - \bar{X})^2 + \mathbb{E}(\bar{X} - X_{\text{true}})^2$$

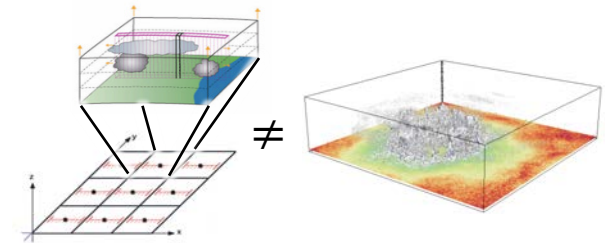


Different parameterizations,
spatial resolutions, etc.

e.g. radiative transfer schemes
(mean rainfall)

Processes ignored in climate models
(e.g. across-scale interactions ?)

e.g. coupling convection-circulation
(extreme rainfall)



How to compute uncertainties when modeling strategies differ?

Different metrics, methods, boundary conditions, forcing and physics
considered

Thank you

William D. Collins
Hossein Parishani
Inez Fung
John Chiang
Travis O'Brien
Jacob Seeley
David Romps
Angeline Pendergrass
Caroline Muller



To read more:

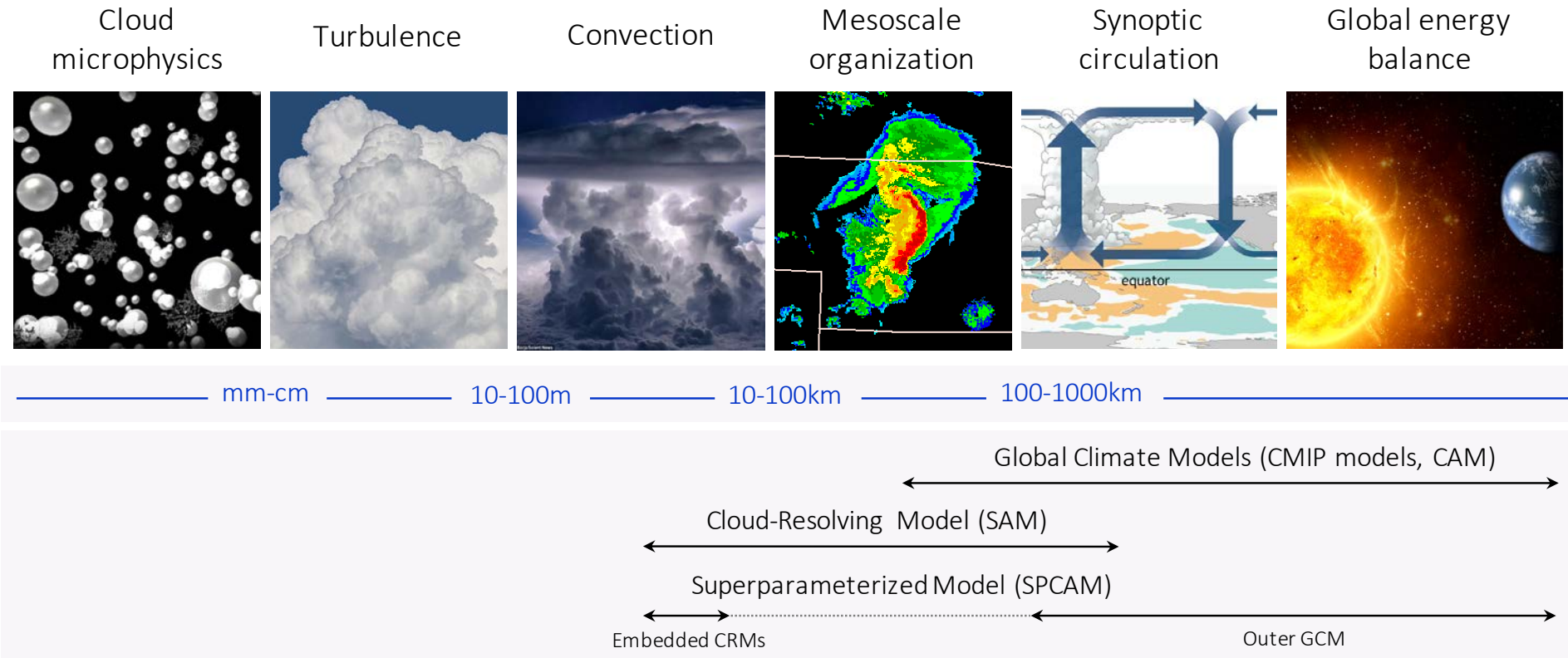


This research was supported by the Director, Office of Science and the Regional and Global Climate Modeling Program of the U.S. Department of Energy and used resources of the National Energy Research Scientific Computing Center (NERSC), also supported by the Office of Science of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.

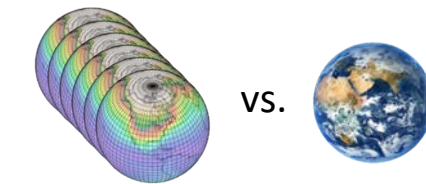
benjamin.fildier@lmd.ens.fr

Uncertainty from resolved and unresolved processes

Processes and scales of interest



Link between processes and global hydrologic uncertainty?



$$\mathbb{E}(X_m - X_{\text{true}})^2 = \mathbb{E}(X_m - \bar{X})^2 + \mathbb{E}(\bar{X} - X_{\text{true}})^2$$

Inter-model variance General bias

model predictions for \bar{P} , P_{99} , ... multi-model mean